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Gigantic oscillations of dc-voltage in semiconductor superlattices

Yu. A. Romanov and *Ju. Yu. Romanova*
Institute for physics of microstructures, RAS, Niznii Novgorod, Russia

Abstract. Electron properties of semiconductor superlattices (SL) in an high-frequency intensive field (harmonic and biharmonic) were studed. We showed that the induced and self-induced transparency states of SL are unstable. Absolute negative conductance, unstable plasma oscillations and parametric amplificatoin of intense field harmonics destroy these states. As a result SL turns in a new state with dc-voltage and (or) non-linear plasma oscillations. The field-dependence of dc-voltage has hysteresis. The gigantic oscillations of dc-voltage arise in SL with high electron concentration. The dissipative chaos and stochastic current oscillations occurs in a very strong field.

There are three types of semiconductor superlattice (SL) transparency: selective transparency, self-induced transparency and induced transparency. Resonant building up of electrons by a harmonic electric field arises in the window of transparency and, therefore, the absorption of the electric field is maximum. The electrons can pass the energy they have taken away from the field not only to the lattice but also to another field and intensify it. This can lead to evolution of the dissipation instability and destruction of the states of transparency. The most efficient destruction mechanisms are the parametric intensification of the strong field harmonics, excitation of growing plasma oscillations and absolute negative conductance (ANC). A SL placed in a strong harmonic field turns either into a steady state or into a self-oscillation regime, or into chaotic state as a result of development of instabilities. The character of transitional processes and the final state depend on the field amplitude and the parameters of the external circuit. We have considered a broken circuit (the SL current is zero) in this paper. The SL behavior is investigated for the given strong static and biharmonic field.

$$E(t) = E_c + E_1 \cos(\omega_1 t + \delta_1) + E_2 \cos(\omega_2 t + \delta_2)$$

Then, using the numerical simulations we investigated the SL behavior in a self-consistent multi-friequency field.

We showed:

1. The transparency states of SL are unstable to quasi-static and plasma oscillations.
2. SL turns into an opaque state without current with the finite static dc-voltage as a result of the destruction of transparency. The states are resistant to quasi-static oscillations, aperiodic instabilities are absent. The stability to high-frequency oscillations depends on the resonant properties of the external circuit.
3. New regions of transparency with nonvanishing static current arise at a given static voltage across the SL. These states are unstable, too.
4. The gigantic oscillations of dc-voltage arise in SL which is in a strong external harmonic field. Their frequency can be controlled by the external circuit parameters and electron concentration.
5. In a general case the states in which SL turns under harmonic field are characterized by dc-voltage and nonlinear plasma oscillations. The dissipative chaos occurs in a very strong field.

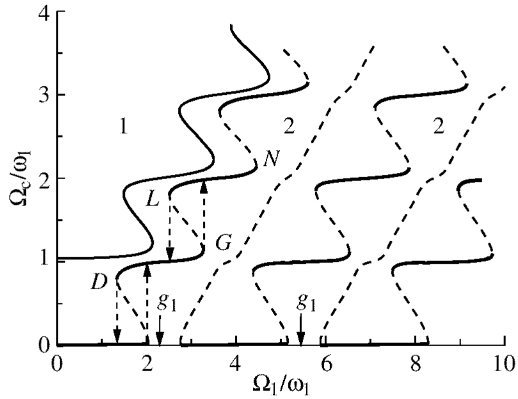

Fig. 1.

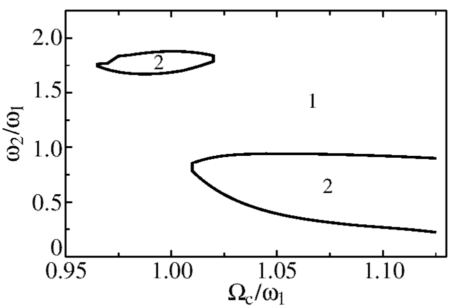

Fig. 2. The regions of negative conductivity (2) on the "step" DG. (1) is the stable region.

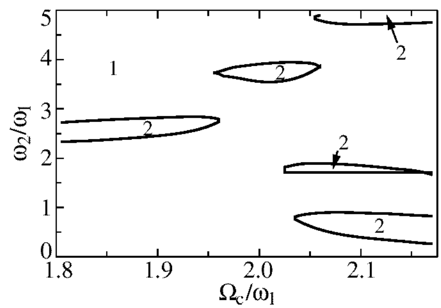

Fig. 3. The regions of negative conductivity (2) on the "step" LN. (1) is the stable region.

Figure 1 demonstrates the instability region (negative conductivity region) for the field E_1—(1) and E_2—(2) under $E_2 = 0$ and for field E_2—(2) under $E_c = 0$. The boundary curves correspond to the non-current states ($j_c = 0$), solid lines are for the steady states. Dashed lines are for the instabilities states: $\Omega_c = eE_c d$, $g_1 = eE_1 d/\hbar\omega_1$, d is the SL period, $\omega_1\tau = 4$, τ is the relaxation time. Existence of g_1-regions with two and more steady states of the static EMF is the main peculiarity of the boundary lines. $V_c = (N\hbar\omega_1/e)n$, $n = 0, \pm 1, \pm 2 \ldots$, N is number of SL periods.

This peculiarity leads to hysteresis in the dependence $Vc(g)$ under slow modification of the amplitude of the strong field. The pointers show an example of hysteresis. Figures 2–3 depict the regions of the negative conductivity on the "steps" DG and LN respectively. They show that SL is not resistant to high frequency only, in the state with $V_c \neq 0$. Spontaneous appearance of static dc-voltage and(or) nonlinear plasma oscillations change the SL conductivity at the frequency of the strong field E_1. This leads to destruction of its transparency, a change in the intrinsic field and, hence, to gigantic ($\sim N\hbar\omega_1/e$) dc-voltage oscillations. The oscillation frequency depends on the parameters of the external circuit and may be rather high.

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